Ka-band and X-band Propagation Through the Solar Corona

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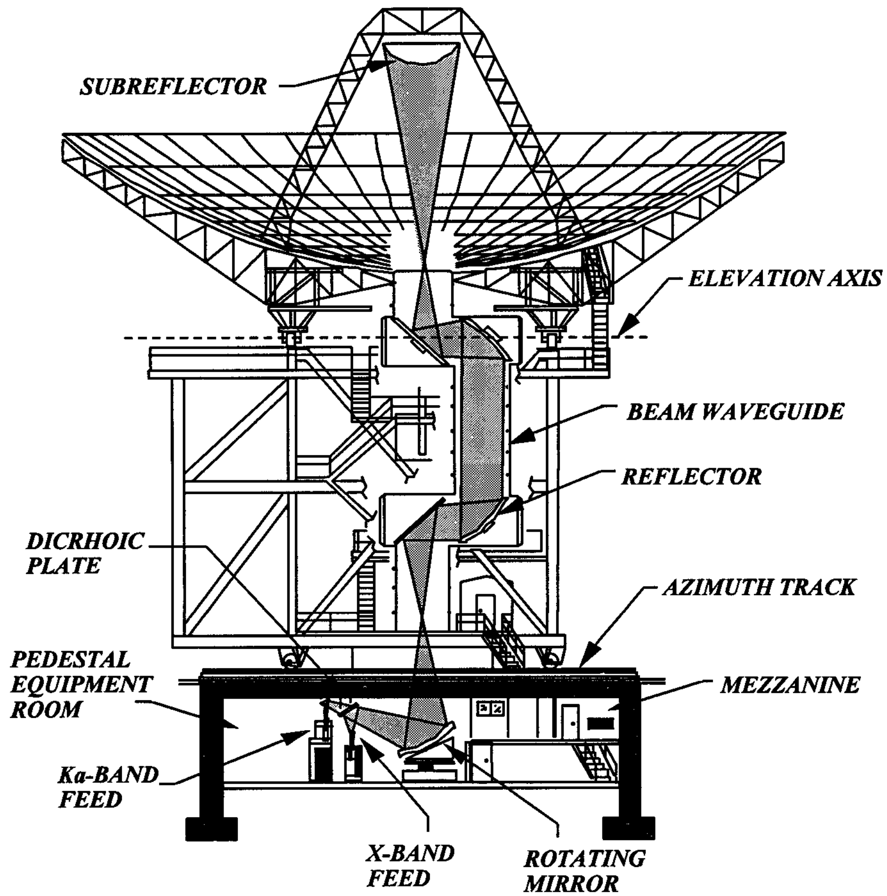
Background

- **This experiment was part of a telecommunications demonstration (MGS/KaBLE-II) to evaluate the advantage of Ka-band (32 GHz) over X-band (8.4 GHz)**
  - Theoretically Ka-band provides an 11.6 dB (factor of 14) advantage over X-band as a telecommunications link frequency
  - In practice, this is reduced to 6 - 8 dB due to increased atmospheric & amplifier noise at Ka-band & antenna imperfections, which are less significant at X-band
  - This link advantage results in spacecraft mass & power savings or higher data rates
- **An analysis of simultaneous Ka-band and X-band Mars Global Surveyor (MGS) data acquired from 1996 to 1998 demonstrated a 6 to8 dB link advantage using a 34-m beam waveguide (BWG) ground antenna**
- **The May 1998 solar conjunction of MGS was the first in which simultaneous Ka-band and X-band data were acquired. The data were analyzed to study solar charged particle effects on the signal propagation for sun-earth-probe (SEP) angles < 3 deg**
  - For spacecraft passages behind the Sun's corona, the signals will encounter degradation due to charged particle density variations
  - Ka-band will have less degradation than X-band and is less likely to drop lock
  - Ka-band suffers less deeper fades

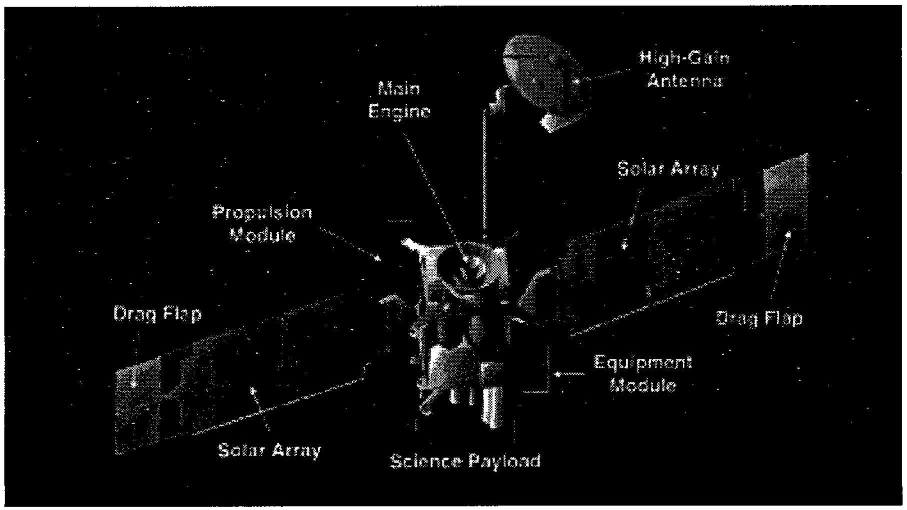
DSS 13 Beam Waveguide (BWG) Antenna

- Constructed as a prototype for the evolving DSN BWG subnet
- Provides a stable environment for feed, receiver and electronics
- Provides easy access to multiple stations at feed ring located in the pedestal room
- Has lower maintenance costs compared to non-BWG antennas
- Is less susceptible to weather (lower attenuation during rain)
- Unique radio science and radio astronomy facility

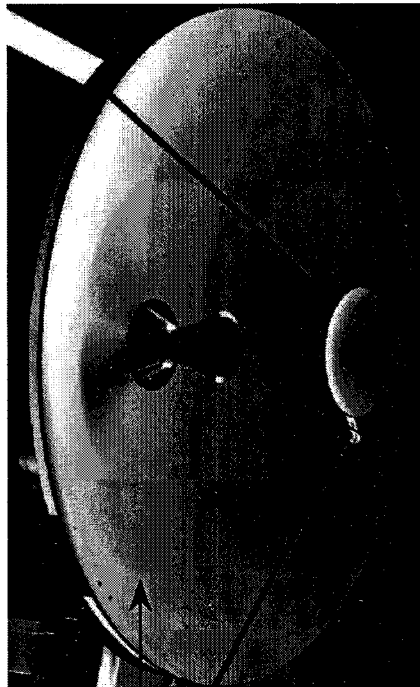


MGS/KaBLE-II Spacecraft Configuration

- The Mars Global Surveyor (MGS) spacecraft carries an experimental Ka-band telecommunications link in addition to the primary X-band downlink
- The Ka/X Signals are simultaneously transmitted from a 1.5-meter High-Gain Antenna (HGA)
- The Ka-band equipment consists of a downconverter, a X4 multiplier, a 1.5W SSPA, and microwave components
- The Ka-band downlink frequency is 3.8 times that of the X-band downlink frequency



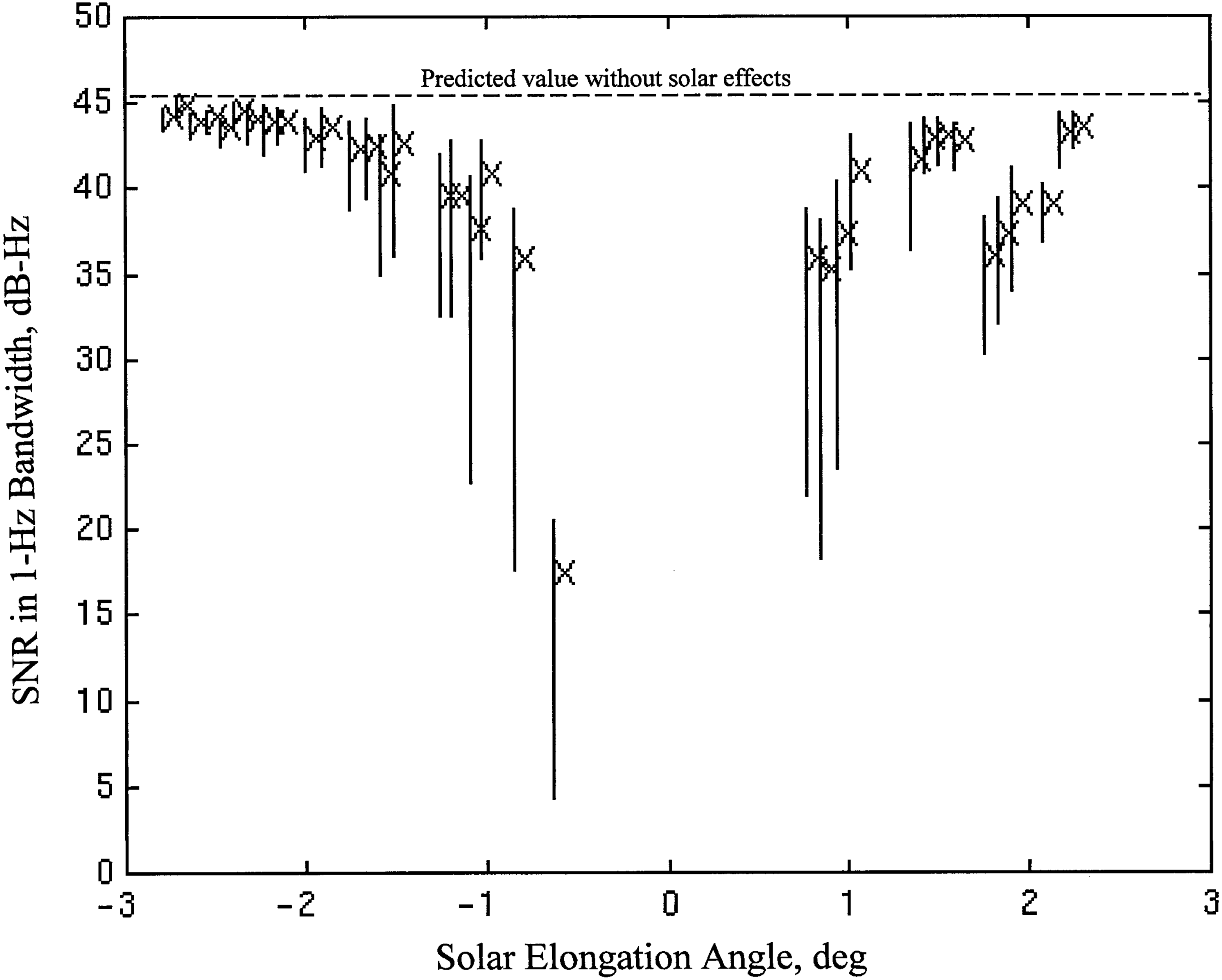
MGS High Gain Antenna with X/Ka-Band Feed



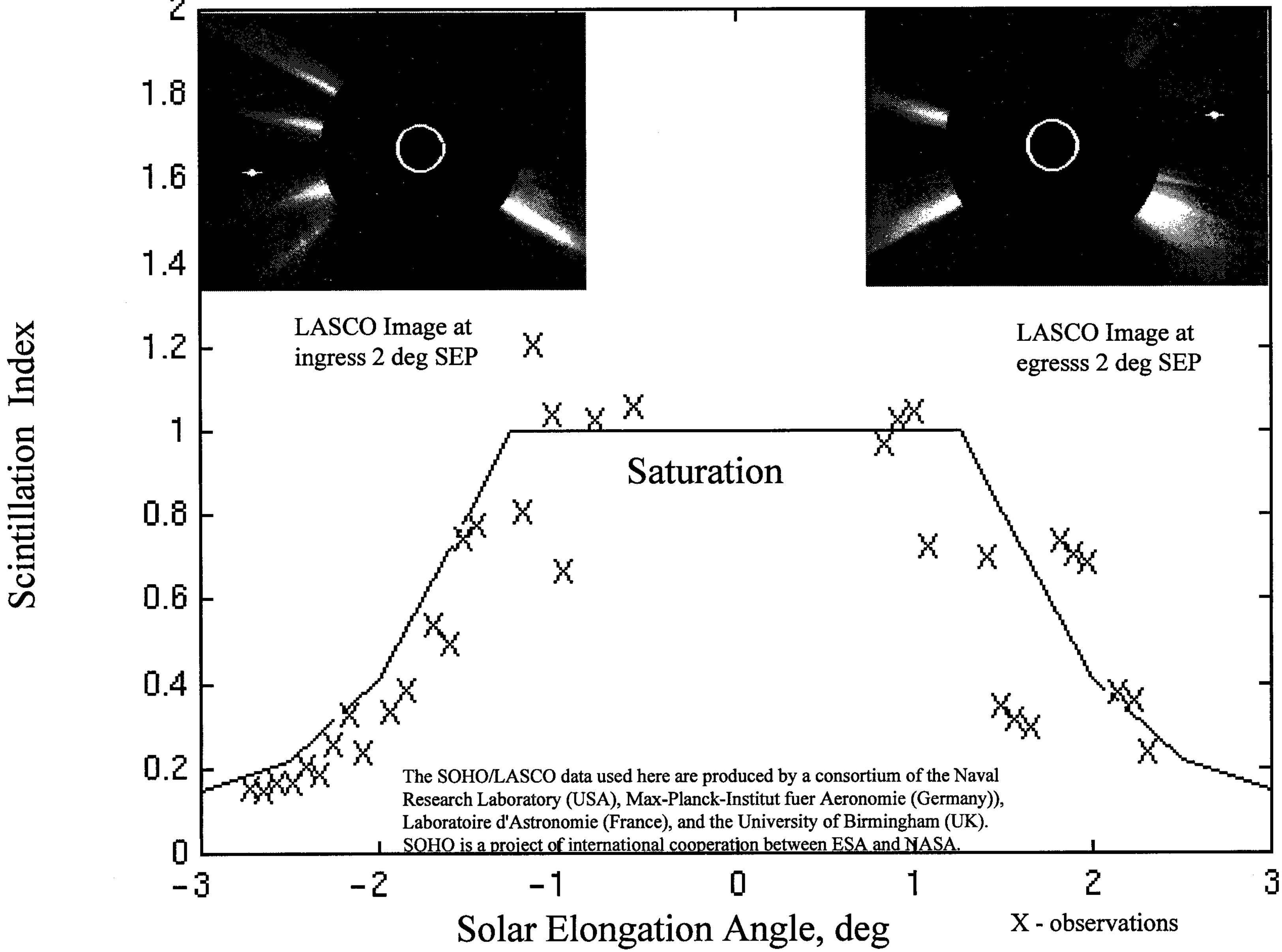
Charged Particle Effects on Signal Propagation

- Reduction of received signal power due to
  - angular broadening (if receive antenna beamwidth is too narrow)
  - spectral broadening (if receiver loop bandwidth is too narrow)
- Increased noise (contribution to Top increases with decreased SEP)
- Scintillation
  - fades on received signal power due to variations of charged particles within signal path
  - $m \sim k^{7/12} c_{no}$ Ref. Woo, R. 1977
  - for the same SEP, Ka-band fluctuations should be less than X-band fluctuations, $m_{Ka} / m_x = 0.15$ (weak scintillation realm)
  - measurements compared with model from J. Armstrong and R. Woo 1980
- Spectral Broadening (Doppler shifts)
  - spread of received signal power with frequency
  - dependent on both electron density fluctuations and solar wind velocity
  - $B \sim (c_{no} k)^{6/5} v$ (Ref. Woo, R. 1977)
  - $B_{Ka} = B_X / 3.8^{6/5} = 0.2 B_X$
  - Useful for scientific purposes when broadening exceeds linewidth of oscillator

Averaged X-band Pc/No vs SEP Angle from BVR at DSN 34-m stations



Measured X-band scintillation index vs SEP estimated from Pc/No acquired from BVR at DSN 34-m stations

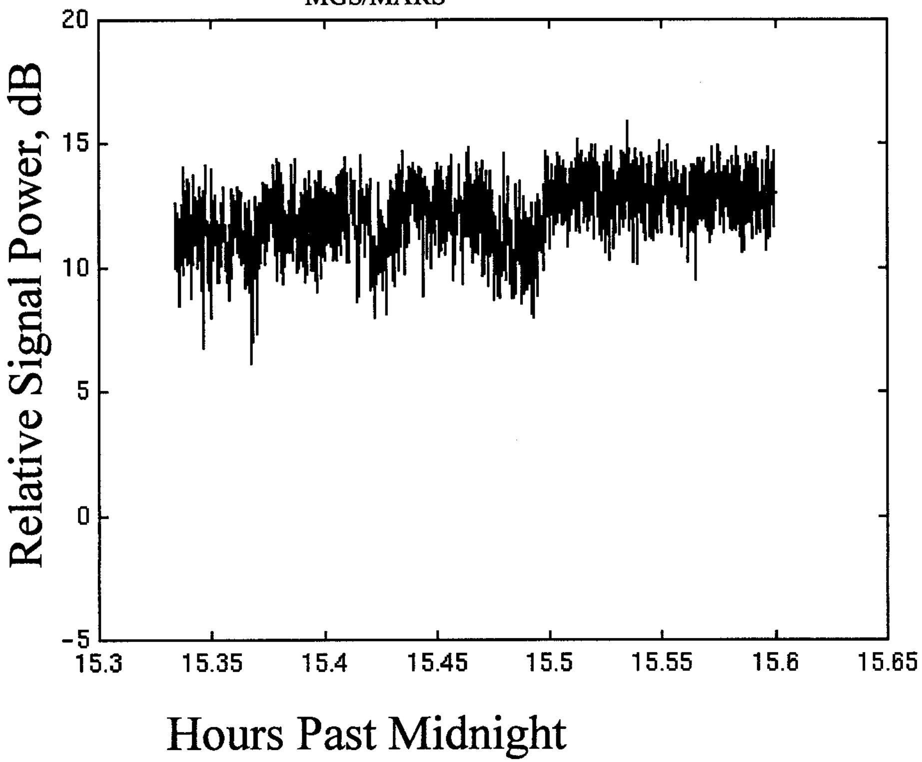


X - observations

Solid line -Armstrong & Woo model

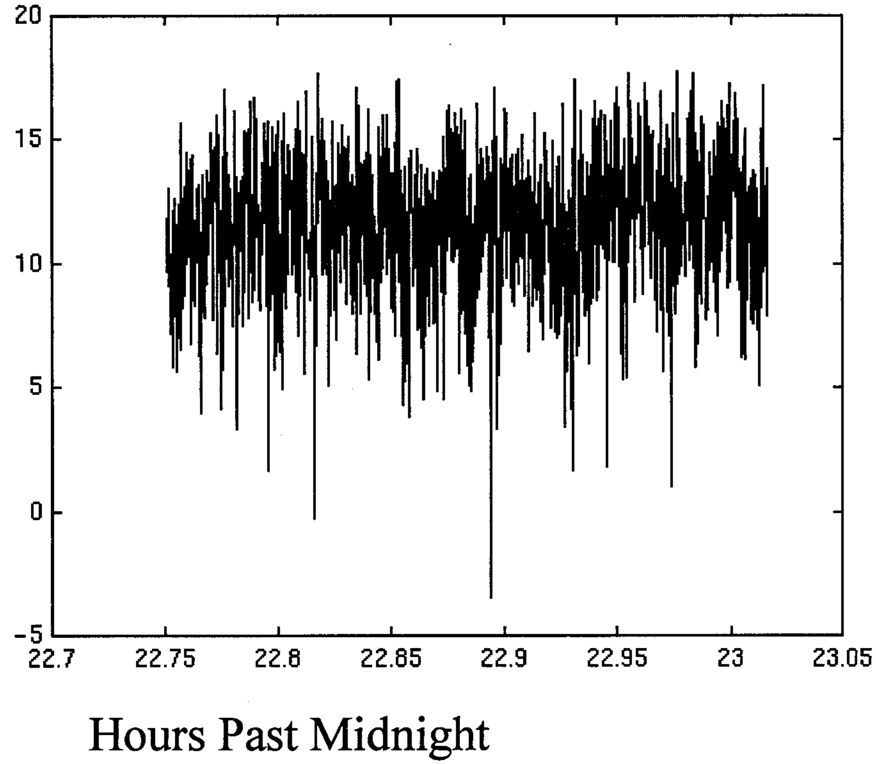
Measured Ka-band Signal Power from FSR at DSS-13

98-125a 15:20-15:36 UTC, SEP = 1.75 deg

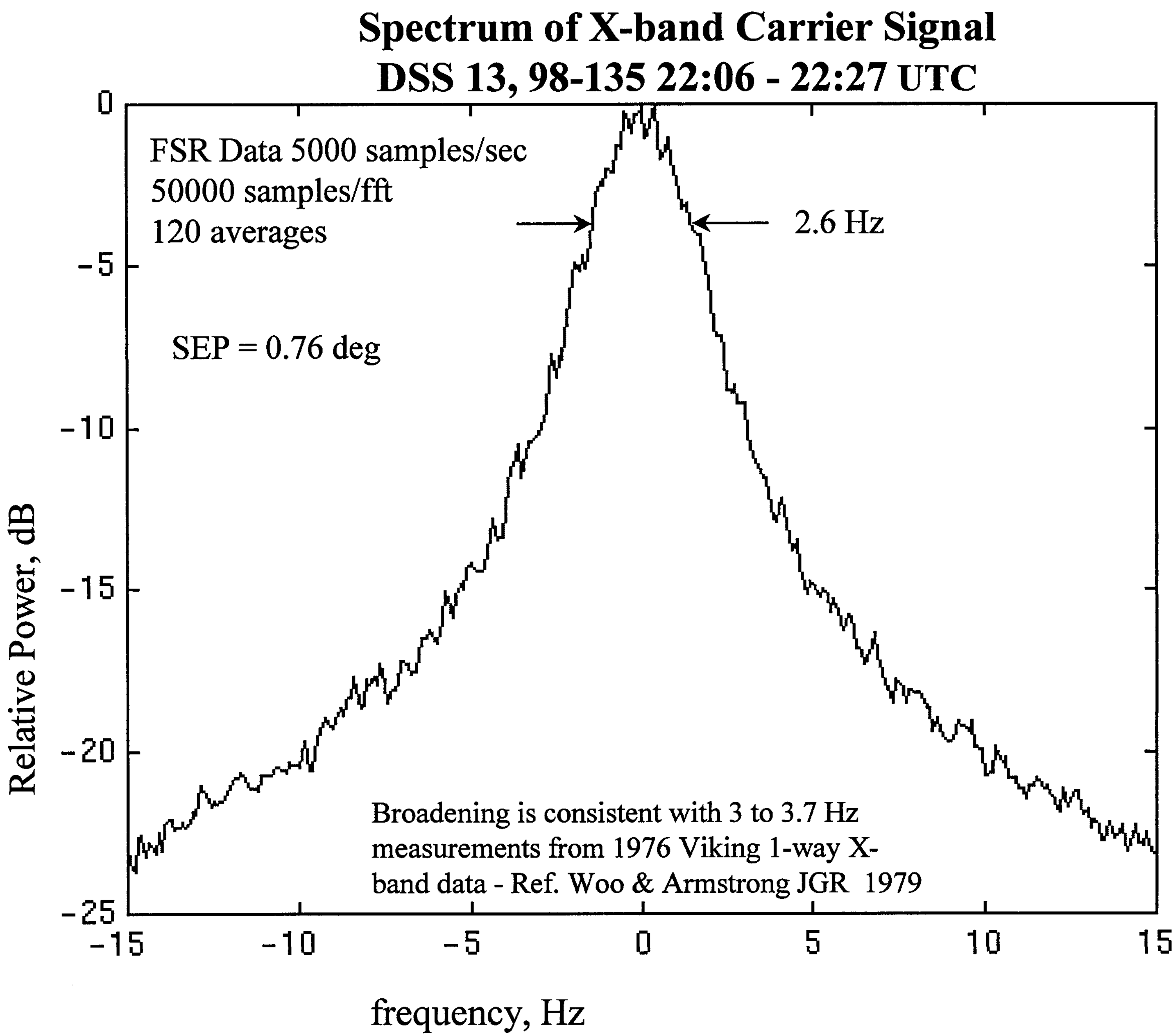


Scintillation Index:
Measured= 0.14
Model = 0.09

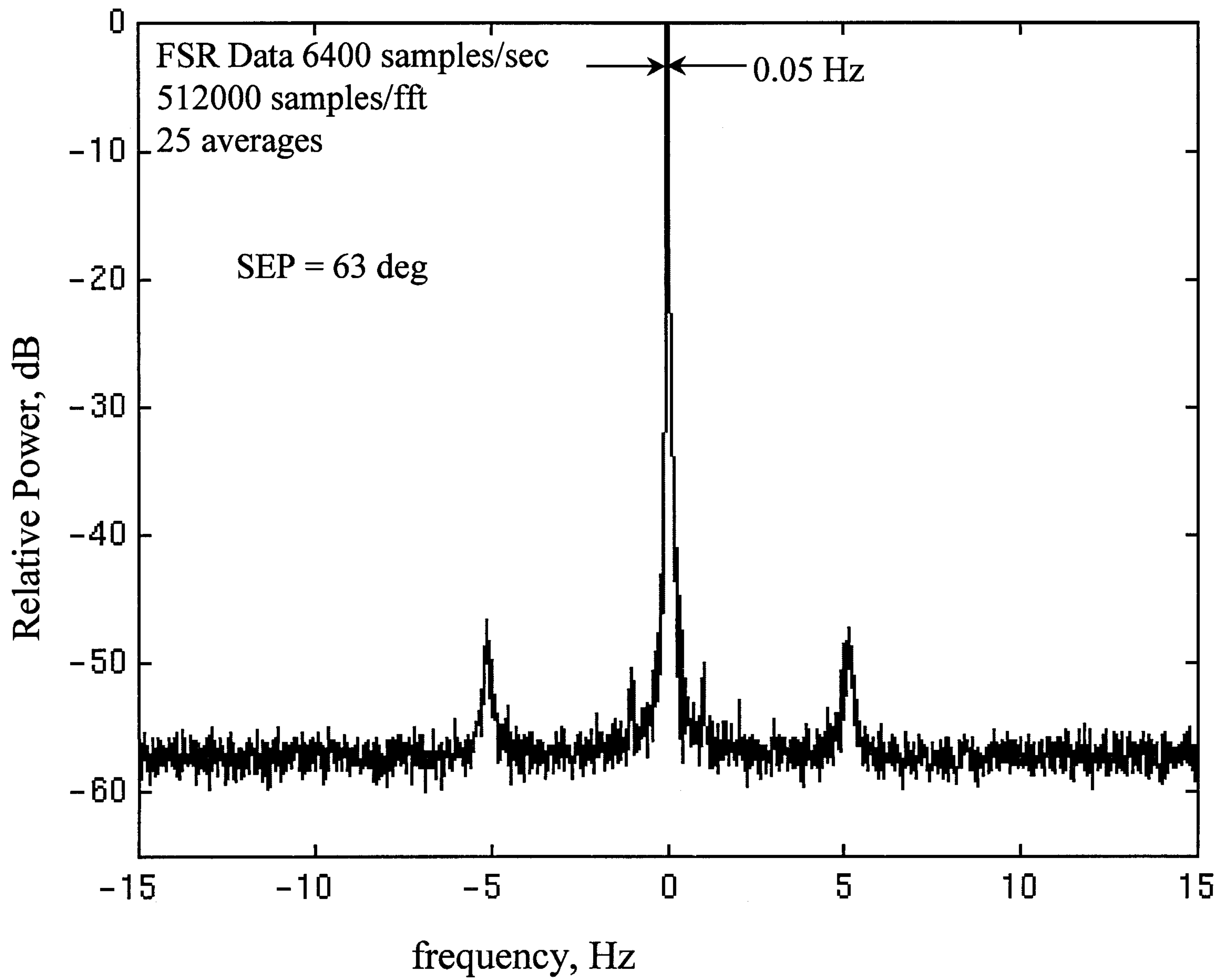
98-128b 22:45-23:01 UTC, SEP = 0.94 deg

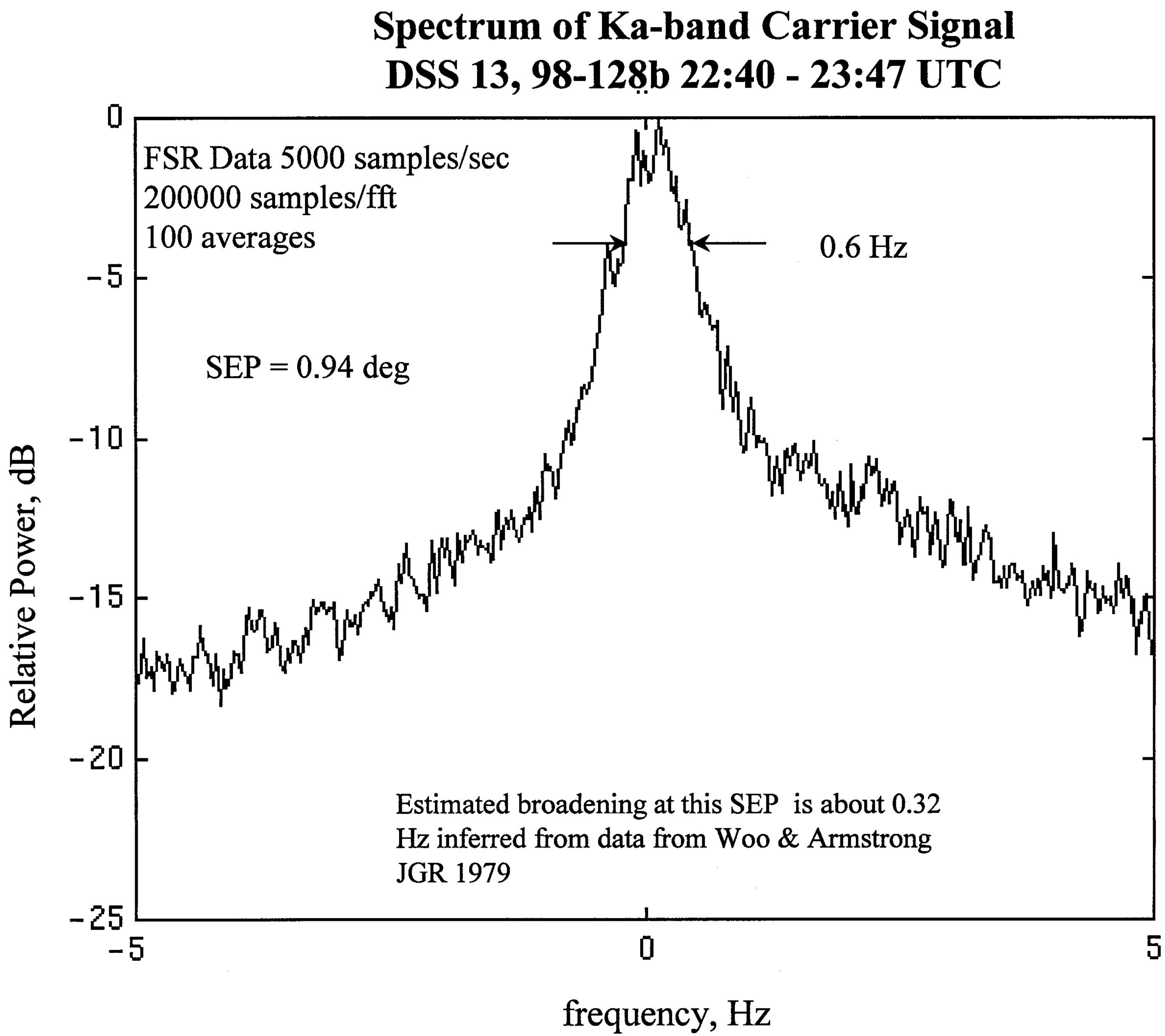


Scintillation Index:
Measured = 0.30
Model = 0.23


Spectrum of X-band Carrier Signal
DSS 13, 98-135 22:06 - 22:27 UTC
FSR Data 5000 samples/sec
50000 samples/fft
120 averages
2.6 Hz
SEP = 0.76 deg
Broadening is consistent with 3 to 3.7 Hz
measurements from 1976 Viking 1-way X-
band data - Ref. Woo & Armstrong JGR 1979
Relative Power, dB
0
-5
-10
-15
-20
-25
-15
-10
-5
0
5
10
15
frequency, Hz

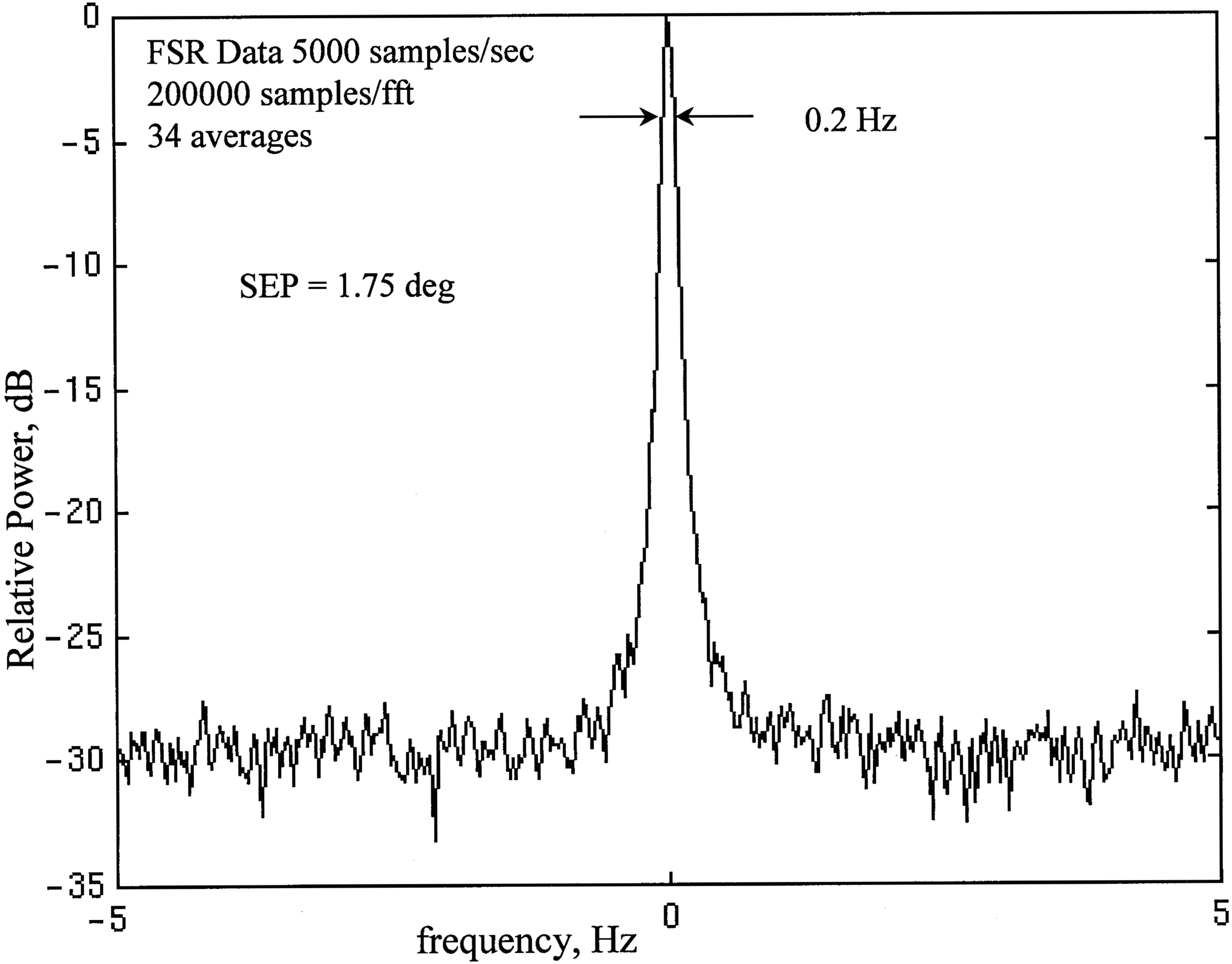
Spectrum of X-band Carrier Signal
DSS 43, 99-303 01:02 - 01:42 UTC



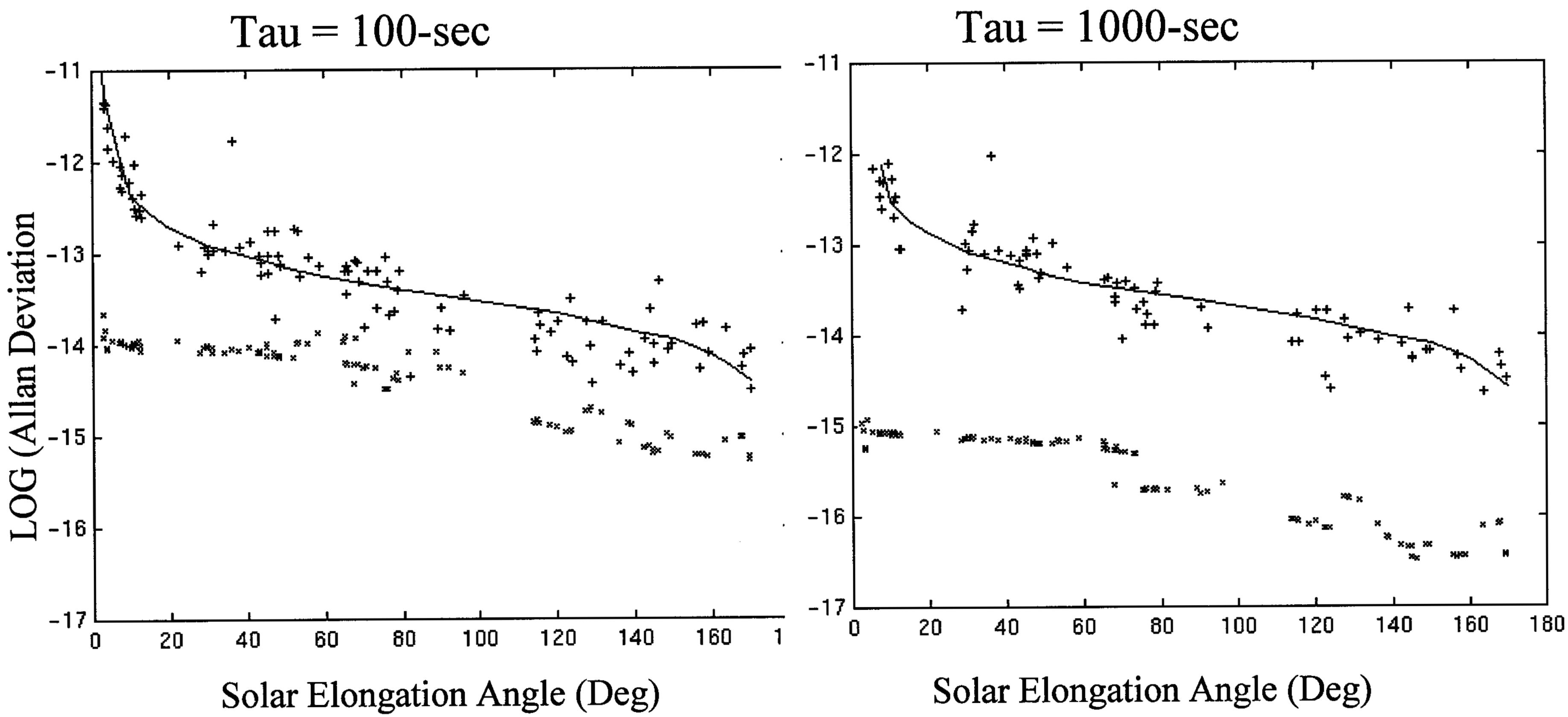


Spectrum of Ka-band Carrier Signal
DSS 13, 98-128b 22:40 - 23:47 UTC
FSR Data 5000 samples/sec
200000 samples/fft
100 averages
0.6 Hz
SEP = 0.94 deg
Estimated broadening at this SEP is about 0.32 Hz inferred from data from Woo & Armstrong JGR 1979
Relative Power, dB
0
-5
-10
-15
-20
-25
-5
0
5
frequency, Hz

Spectrum of Ka-band Carrier Signal
DSS 13, 98-125a 15:20 - 15:36 UTC



X/Ka Frequency Difference Allan Deviation vs SEP Angle



Symbol Key -

\+ Measurements from MGS KaBLE-II Freq Data Allan Dev at 1000-s of (fx -- fKa/3.8)
* Estimates from Thermal Noise using Pc/No
Solid curve - Fitted model From Armstrong et. al. 1979, using Viking S-band/X-band data acquired between 1976.3 to 1978.3 (scaled appropriately)

Conclusions

- MGS Solar Conjunction May 1998 was first in which simultaneous Ka and X-band data were acquired
- The effects of charged particles on the Ka-band carrier signal versus SEP behaved in way consistent with predicted behavior based on models estimated from previous solar conjunction data at other frequencies (extrapolated to Ka-band)